Complications of Image-Guided Thermal Ablation of Liver and Kidney Neoplasms

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Semin Intervent Radiol 2014;31:138–148

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Abstract

Keywords

- complication
- ablation
- liver
- kidney
- neoplasm
- interventional radiology

Image-guided thermal ablation is a widely accepted tool in the treatment of a variety of solid organ neoplasms. Among the different techniques of ablation, radiofrequency ablation, cryoablation, and microwave ablation have been most commonly used and investigated in the treatment of liver and kidney neoplasms. This article will review complications following thermal ablation of tumors in the liver and kidney, and discuss the risks and clinical presentation of each complication as well as how to treat and potentially avoid complications.

Objectives: Upon completion of this article, the reader will be able to describe management of complications, and methods to avoid them, in the thermal ablation treatment of liver and kidney tumors.

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Image-guided tumor ablation with use of thermal energy has been widely used for the treatment of liver and kidney malignancies. The common techniques of ablation include radiofrequency ablation (RFA), microwave ablation (MWA), and cryoablation.^{1–14} RFA has been the most commonly used and investigated technique in the treatment of liver malignancies. The efficacy and safety of RFA have been reported in the literature, and RFA has been considered as the first choice of ablation therapy for liver malignancies.^{4,15,16} Recently,

MWA has received attention due to the potential of microwave energy to produce faster heating over a larger volume of tissue with less susceptibility to heat-sink effects.^{5,17–22} Cryoablation is less commonly used in the liver than RFA or MWA because it requires placement of multiple cryoprobes and does not allow tract ablation, raising concern for an increased risk of bleeding. In addition, there are other risks of serious complications such as cryoshock and parenchymal crack when cryoablation is performed, especially in the liver.^{18,19,23} In the treatment of small renal tumors, RFA and cryoablation are the two most commonly used ablation techniques, and each has the potential for renal parenchymal preservation with lower morbidity compared with open surgical tumor resection.^{7,9,11,24–26}

Although image-guided thermal ablation has been accepted as a promising nonsurgical treatment for liver and kidney malignancies, the risks of the procedure must be considered as part of the therapeutic decision-making process. Early detection and proper management of complications are essential, and knowledge about potential complications may help the practitioner avoid significant injury to the patient. Major complications are defined as events that lead to substantial morbidity and disability, increasing the level of care, or resulting in hospital admission or substantially lengthened hospital stay. These include any cases in which

a blood transfusion or additional interventional procedure is required. All other complications are considered minor. Several complications can be classified as either a major or minor complications, depending on severity. Side effects are expected undesired consequences of the procedure that, although occurring frequently, rarely result in substantial patient morbidity. These include pain, postablation syndrome, asymptomatic pleural effusion, and minimal asymptomatic perihepatic (or perirenal) fluid or blood collections.¹⁴ This review will discuss the complications and side effects of thermal ablation in the treatment of liver and kidney malignancies.

Liver

The liver has been the most studied target organ for thermal ablation of both primary and metastatic malignancies. There have been substantially more data in terms of the complications that occur with liver ablation than in any other site. Overall, the rates of major complications and mortality are low with thermal ablation of liver malignancies, with mortality reported in 0 to 1.4% of cases and major complications in 2.2 to 5.7% of cases.^{1,15,27-40} In contrast, the mortality and major complication rates of MWA have been reported as 0 to 0.4% and 2.6 to 4.6%, respectively.^{1,15,32,34,39} In recent studies, the types and incidences of complications caused by RFA and MWA of liver malignancies are similar and comparable in the clinical setting.^{15,34} Causes of death have included intestinal perforation, portal vein thrombosis, liver failure, septic shock, and massive hepatic hemorrhage.^{29,31,37,38} Major complications include hemorrhage, liver failure, injuries to bowel and biliary tree, infections such as abscesses and peritonitis, vascular thrombosis and hepatic infarction, pleural complications (pneumothorax, hemothorax, large effusion requiring drainage), biliary strictures, bilomas, cholecystitis, broncho-biliary fistulas, arteriovenous fistula leading to rapid tumor dissemination, skin burns, and tumor seeding.^{1,15,27-41} These complications are discussed below.

Vascular Complications

Hemorrhage is one of the most common major complications encountered with hepatic thermal ablation. Overall, the risk of significant bleeding is low (< 2%), but it is influenced by the status of the underlying hepatic parenchyma and the tumor location.²⁹ Coagulopathy in cirrhotic patients is the most important risk factor for bleeding. Other risk factors include the location of the tumor adjacent to a major blood vessel, and the use of multiple punctures or multiple needles (RFA electrodes or MWA antennas).^{30,40} Bleeding is generally intraperitoneal, but it can be subcapsular, intralesional, or into the pleural space. Most venous bleeding tends to be self-limited and can be managed conservatively; blood transfusion, transarterial embolization, or surgery may be necessary in cases of arterial bleeding.^{29,30}

To prevent significant hemorrhage, any significant coagulopathy must be corrected before and after the procedure. In addition, the practitioner should try to minimize the number of transgressions of the liver capsule, and every effort should

be made during needle placement to avoid traversing major vessels and by traversing at least some normal hepatic parenchyma. With both RFA and MWA, cauterization of the needle tract after ablation can be performed to reduce the risk of hemorrhage.³⁰ One other technique has been described for patients who may be at increased risk for hemorrhage. Takaki et al reported using a combination of arterial embolization before RFA that increased the size of ablation zone by reducing arterial blood supply and significantly decreasing the incidence of major hemorrhage.³¹

Aside from hemorrhage, other potential vascular complications include portal venous thrombosis (▶ **Fig. 1**), hepatic venous thrombosis, hepatic infarction, arteriovenous fistula, and hepatic artery pseudoaneurysm.^{28-30,37,38,40,42,43} The reported incidences of portal venous thrombosis and hepatic venous thrombosis are 1.7 and 1.4%, respectively.^{29,38} Portal vein thrombosis normally will manifest soon after the procedure. Smaller caliber vessels (< 3 mm) tend to be more prone to thrombosis from thermal injury due to the absence of a vascular perfusion-mediated heat-sink effect that is largely dependent on the size of the vessel. Thermal damage may cause thrombosis even in relatively large vessels if the blood flow is decreased, such as during the Pringle maneuver (clamping of porta hepatis to interrupt hepatic arterial and portal venous flow to the liver).^{40,44-46} Ding et al reported a case of percutaneous MWA in a patient with portal venous thrombosis.¹⁵ In this case, the ablated tumor was in close proximity to the portal vein, and because of underlying cirrhosis, there was reduced portal flow. When vessel thrombosis does occur following percutaneous ablation, treatment is tailored to the individual circumstance. Often, thrombi within portal and hepatic veins will require no specific therapy, but systemic anticoagulation or local thrombolysis may be necessary if liver function is affected.^{28,40}

Hepatic infarction is an uncommon complication of thermal ablation, likely because of the dual blood supply to the liver as well as the liver's ability to develop extensive collateral pathways.^{29,37,40,47} A large case review conducted to specifically evaluate the frequency of hepatic infarction following RFA demonstrated hepatic infarction in 20 of 1,120 sessions (1.8%).⁴⁷ Most of these patients were managed conservatively, and the infarcted tissue resolved. However, there were accompanied complications in six cases including biloma ($n = 2$), abscess ($n = 2$), portal vein thrombosis ($n = 1$), and death from hepatic failure related to lobar infarction ($n = 1$).

Biliary Complications

Complications of bile leakage and biloma formation following thermal injury to the biliary tree typically occur in patients with lesions located adjacent to the bile duct (▶ **Fig. 2**).^{15,30} Major bile ducts near the hepatic hilum are generally considered to be protected from thermal damage by the heat-sink effect of the portal vein. However, if the blood flow in the portal vein is reduced because of the Pringle maneuver, cirrhosis, or portal vein thrombosis, the risk of bile duct injury increases. Thermal ablation of lesions near the hepatic hilum is challenging because the complete ablation of the

Figure 1 (A) Axial arterial phase postcontrast T1 MR image of the abdomen demonstrates a segment VIII early enhancing lesion (large arrow) adjacent to a branch of the right portal vein (arrowhead). This arises within a site of previously ablated hepatocellular carcinoma (small arrows). (B) Coronal delayed phase postcontrast T1 MR image of the abdomen demonstrates washout and late capsular enhancement of the segment VIII lesion (large arrow), adjacent to the right portal vein (arrowhead). The previously ablated hepatocellular carcinoma is again noted laterally (thin arrows). (C) Axial postcontrast CT image performed during microwave ablation demonstrates the ablation antenna (arrowheads) adjacent to the right portal vein (arrow). (D) Coronal delayed postcontrast T1 MR image of the abdomen acquired 1 month after ablation demonstrates hypoenhancement of the ablation site (arrows) with expansile, nonenhancing acute thrombus within the portal venous system (arrowheads). CT, computed tomography; MR, magnetic resonance.

Figure 2 (A) Axial arterial phase MR image demonstrates an early enhancing lesion in segment VIII (arrow) that also showed washout on delayed imaging (not shown), compatible with hepatocellular carcinoma. (B) Coronal noncontrast-enhanced reformatted CT image during microwave ablation demonstrates an ablation antenna (arrowheads) adjacent to a localizer coil (arrow) that was placed during contrast administration. (C) Coronal thick slab MRCP image acquired 4 months postablation demonstrates dilated intrahepatic ducts (arrowheads) with a normal common bile duct (thin arrow). There is also heterogeneous necrosis and cystic change in the ablation site (thick arrow). (D) Image during a percutaneous transhepatic cholangiogram from a left-sided approach demonstrates a dilated left biliary tree (arrowheads) that leads to a stenosis near the confluence of the left and right hepatic ducts (large arrow). A plastic biliary stent is present in the common bile duct (small arrows). CT, computed tomography; MR, magnetic resonance; MRCP, magnetic resonance cholangiopancreatography.

tumor and the protection of major bile ducts or portal venous branches are frequently incompatible goals.^{15,30,40} If necessary, it is possible to treat lesions adjacent to large bile ducts. In this situation, however, the practitioner may consider cooling the bile duct via an endoscopic nasobiliary drainage tube or intraoperatively placed bile duct catheter to prevent thermal injury to the bile duct.^{48,49} When biliary injury does occur, a bile duct stricture is the typical result. When the stricture affects a peripheral bile duct, it tends to be asymptomatic.^{30,40} No treatment is necessary in asymptomatic patients, but percutaneous or endoscopic drainage may be necessary for more severe cases, particularly if the patient develops jaundice, cholangitis, or abscess.

Hepatic abscess is one of the most common major complications after percutaneous thermal ablation in the liver with an overall risk of 0.3 to 2% (►Fig. 3).^{28,29,31,37,38} Two important risk factors for abscess formation are recognized: bacterial colonization of the biliary tract and diabetes mellitus. Colonization of the biliary tract may take place through a bilioenteric anastomosis, endoscopic sphincterotomy, biliary stent, or pneumobilia of unknown origin.^{15,40} Although prophylactic use of antibiotics is controversial, many practices routinely use antibiotics in patients with bilioenteric anastomosis.^{30,38,40,50} If an abscess does develop following percutaneous ablation, it is typically managed similar to abscesses from other etiologies. Smaller abscess can often be managed

with antibiotic therapy alone, whereas larger abscesses will require percutaneous drainage.

Extrahepatic Complications

Extrahepatic complications of liver ablation include direct penetration and thermal injury to adjacent organs, needle tract seeding, and thermal effect upon remote organs.^{29,40} Pneumothorax and hemothorax, which are related to the image-guided placement of needles, are rare but may be encountered when treating lesions near the dome of the liver, particularly when a transpleural approach is used (►Fig. 4).^{29,30,40} A chest radiograph should be performed anytime chest pain or dyspnea occurs following an ablation. In this situation, pneumothorax and hemothorax are usually self-limited.⁴⁰ However, if the patient becomes symptomatic or if there is suspicion for an active air leak, a thoracostomy tube may be needed. In addition, when treating lesions in the dome of the liver, the risk of diaphragmatic injury is increased. Although most diaphragmatic injuries are self-limited, the diaphragm may become thinner and weaker as a result of the injury. In patients with elevated intra-abdominal pressure, such as a cirrhotic patient with ascites, the combination of increased abdominal pressure and a weakened diaphragm may lead to a diaphragmatic hernia.^{15,30}

Gastrointestinal injury is an uncommon complication of hepatic thermal ablation, but is particularly important given

Figure 3 (A) Preablation contrast-enhanced MRI demonstrates an area of early enhancement (arrow) in segment IVa that demonstrated washout and late capsule enhancement (not shown), worrisome for hepatocellular carcinoma in this patient with hepatitis C and cirrhosis. (B) Noncontrast-enhanced CT acquired 2 weeks after ablation (done noncontrast due to acute renal failure) demonstrates a fluid and gas collection in the ablation bed (arrow). (C) Image from a more caudal location as B demonstrates a small amount of biliary gas (arrow), suggesting communication of the abscess cavity with the biliary tree. (D) Noncontrast-enhanced CT of the abdomen following percutaneous drainage of the abscess demonstrates resolved abscess cavity in the ablation bed with the pigtail drain still visible (white arrow). CT, computed tomography; MRI, magnetic resonance imaging.

Figure 4 (A) Axial postcontrast T1 MR image in the lower abdomen demonstrates a heterogeneously early enhancing mass in segment VI (arrow), suspicious for hepatocellular carcinoma. (B) Lung window images after repositioning of the ablation electrode (arrowheads) into the segment VI lesion demonstrate a small pneumothorax (arrow). (C) Axial CT image following chest tube placement after the pneumothorax enlarged on subsequent images during ablation. CT, computed tomography; MR, magnetic resonance.

its severity.^{29,37,38,51} The colon is considered to be at especially high risk for perforation due to its relatively thin wall and fixed position. The stomach and small bowel are thought to be less heat sensitive because of thick gastric wall and peristalsis of the small bowel.^{29,30,40} Adhesions from prior surgery or chronic cholecystitis also contribute to the risk of bowel perforation by limiting bowel motility.^{29,32} The reported incidence of colon perforation is estimated between 0.1 and 0.3%.⁵¹ Although the exact safety margin has not been defined, a minimum distance of 1 cm between the ablation

zone and bowel wall has been suggested to be sufficient to prevent bowel injury.^{29,32,51,52} Multiple techniques have been proposed to protect the bowel against thermal damage during ablation procedures. The least invasive method involves positioning of the patient in the right anterior oblique position, so as to allow gravity to draw the hepatic flexure of colon away from the liver surface.⁵¹ Should this not work, one can attempt to displace the bowel loops from the liver surface^{51,53}; this can be accomplished through hydrodissection, a technique where 5% dextrose water or carbon dioxide is injected into the peritoneal cavity between the lesion and the bowel. The use of ionic solutions, such as saline, should be avoided with RFA due to the propensity of such solutions to conduct rather than insulate current. Another method of displacement involves using a balloon catheter that is placed between the liver surface and the bowel loops. Either independently or in conjunction with the above techniques, one can place independent thermometers to monitor temperatures near critical structures in real time during ablation.^{28,54} If the temperature becomes significantly elevated, either the ablation probe can be repositioned or the procedure can be stopped. Management of gastrointestinal tract injuries includes fasting, antibiotic therapy, and drainage of any subsequent abscess. Surgery may be required if the injury does not heal and results in peritonitis.⁴⁰

Cholecystitis may occur with thermal ablation of a mass adjacent to the gallbladder. Although minimal wall thickening is often seen on follow-up imaging, symptomatic cholecystitis or gallbladder perforation is very rare, because fluid content in the gallbladder lumen plays a role in dissipation of heat around the gallbladder fossa.^{30,40}

Tumor seeding from the needle tract is extremely uncommon, with rates reported from 0.3 to 4% (**Fig. 5**).^{29,30,38,40,42,55–58} There are several factors that may increase the risk of tumor seeding, including poor tumor differentiation, subcapsular location, prior percutaneous biopsy, multiple treatment sessions, and placement of multiple needles.^{28–30,42,59,60} To avoid needle tract seeding, the number of punctures and repositioning of the needle should be minimized, and the needle should be placed in such a way that traverses sufficient normal hepatic parenchyma. Cauterization of the needle tract may be effective for the prevention of needle tract seeding, especially in the case of a subcapsular tumor.^{29,30,40} Because seeded tumors tend to grow very slowly, a long follow-up period is necessary to exclude this complication.⁴⁰ When it does occur, the treatment will depend on the exact size and location, but there are reports of successful management with thermal ablation.^{58,60}

In addition to local thermal injury predicted near the site of ablation, distant thermal injury is another potential complication.^{1,28,30,42,61,62} Monopolar radiofrequency electrodes require grounding pads to complete the high-current radiofrequency circuit, and the same amount of current is deposited at the grounding pad as the electrode itself. This puts the grounding pad sites at risk for thermal injury, and severe burns have been reported in early studies of RFA. From that experience, it was realized that to disperse the energy more effectively, larger grounding pads were necessary. Because

Figure 5 (A) Axial postcontrast T1 MR image of the abdomen demonstrates an early enhancing lesion in segment VII (arrow) that demonstrated later washout and capsular enhancement (not shown), compatible with hepatocellular carcinoma. (B) Oblique coronal ultrasound image of the liver during radiofrequency ablation demonstrates the radiofrequency electrode (arrowheads) placed into the segment VII lesion (arrow and measurement). (C) Although no CT images were obtained of the radiofrequency electrode in place, the preablation CT scan shows the laterally placed skin marker sheet (arrow), with the anticipated skin entry site in this region. (The lesion was not visible on this noncontrast CT). (D) Axial postcontrast T1 MR image of the abdomen acquired 22 months after radiofrequency ablation demonstrates an enhancing mass (arrow) between the lateral ribs, compatible with ablation tract seeding. CT, computed tomography; MR, magnetic resonance.

larger grounding pads have become routine, the incidence of skin burns has become much lower.^{28–30} To minimize the risk of grounding pad burns, the pads need to be placed in full contact with the skin, relatively far away from the electrode and equidistant from it, to allow for more even heat distribution. Excess hair should be removed from the skin to facilitate full grounding pad contact.^{28–30} Although microwave does not require grounding pads, significant skin burns have been reported at the skin exit site with the use of noncooled antennas.³² There is even a report of skin burn with use of cooled antenna due to prolonged cauterization of the needle tract when the antenna was withdrawn.¹

Side Effects of Hepatic Ablation

Side effects of hepatic thermal ablation include pain, asymptomatic pleural effusions, asymptomatic perihepatic fluid or hemorrhage, minimal thermal damage to adjacent structures, loose stool, and postablation syndrome. Postablation syndrome refers to a constellation of symptoms that has been observed following thermal ablations in 32 to 58% of patients.^{63–65} It is characterized as a self-limited flu-like illness with low-grade fever, malaise, nausea, and/or vomiting, and it is thought to be mediated by an inflammatory response to necrotic tissue that results from ablation.⁶³ Most of the data suggest that the occurrence and severity of postablation syndrome are related to the volume of necrotic tissue created by the ablation.^{63–65} Andreano et al⁶³ reported in a study using MWA that the incidence and symptomatology of postablation syndrome seen with hepatic MWA is similar to that

reported with RFA. These authors also mentioned that postablation pain was best predicted by the volume of ablation, total ablation time, and increases in serum aminotransferase levels.⁶³ Although fever is the most common manifestation of postablation syndrome, any fever after 2 weeks should prompt consideration of an underlying infection.^{29,30}

Kidney

As the incidental detection of small renal masses has increased with the use of cross-sectional imaging for other indications, nephron-sparing techniques such as open or laparoscopic partial nephrectomy, RFA, and cryoablation are increasingly being employed in an attempt to decrease morbidity and preserve renal function in patients with early-stage renal cell carcinoma.^{9,29,66,67} Kidney ablation is quite different from liver ablation. Adjacent heat- or cold-sensitive structures are more common with kidney ablation due to proximity of the bowel and ureter, and the smaller size of the organ.⁴² Overall, the rates of major complications with renal ablation are 2 to 6%.^{24,25}

RFA and cryoablation are the two most commonly used ablation techniques. Each has unique technical features and neither is clearly superior to the other.²⁴ There also does not appear to be a difference in complication rates between the two technologies. In a large series of 573 procedures, Atwell et al⁶⁸ compared the incidence of major complications between RFA and cryoablation and found no statistical difference (the incidence with RFA was 4.7% and with cryoablation was 7.7%).

Within this study, nerve and urothelial injury were more commonly seen in the RFA group, and bleeding and hematuria were more common in cryoablation group. In general, increased tumor size and central tumor location were associated with higher complications rates.⁶⁸

Vascular Complications

Hemorrhage is the most commonly encountered complication following renal ablation (►Fig. 6). Massive bleeding requiring blood transfusion is reported to have an incidence of 1 to 2%.^{69–71} Unlike RFA, cryoablation does not cauterize or coagulate vessels; thus, hemorrhage at the ablation zone immediately after probe removal is a risk of cryoablation. Therefore, the patients' coagulation profile should be corrected before and after the procedure.⁹ In general, conservative management or blood transfusion alone is enough for the treatment of bleeding, as it tends to tamponade, but transarterial embolization may be required in patients with severe blood loss or uncorrectable hypotension. In select patients, some authors advocate prophylactically embolizing larger and/or more centrally located tumors to decrease the risk of hemorrhage.^{68,72}

Hematuria following renal ablation occurs infrequently and is usually self-limited, resolving within 12 to 24 hours. Hence, a single episode of hematuria is not a clinical problem, especially if it progressively clears. Nevertheless, in cases of more significant hematuria, bladder outlet obstruction may result from clot formation; this is typically treated with bladder irrigation.^{9,42,69}

Perinephric hematomas may occur during ablation (< 5%). Hematomas of 1 cm or smaller are common and typically of no clinical consequence, and even larger perinephric hematomas are generally self-limited.^{9,42}

Renal infarction rarely develops following ablation. A segmental infarction is not clinically significant in patients with good baseline renal function but may cause renal insufficiency in patients with marginal renal function. Renal infarction may also result from thermal injury to a small artery adjacent to a renal mass.^{69,73}

Renal Collecting System Complications

Inadvertent injury of the proximal ureter during renal ablation has been associated with formation of a urinoma, ureteral obstruction, and chronic stricture (►Fig. 7). The incidence of ureteral thermal injury is 1 to 2%. A renal mass in the medial aspect of the lower pole kidney frequently is in close proximity to the ureter, which can become constricted from thermal injury.^{9,69} Similar to other organs, the precise safe distance from the ureter has not been determined. Still, it has been suggested that ureteral injury can be avoided when the ureter is located more than 2 cm from the ablation zone.⁶⁹ When one is faced with the potential of ureteral injury during renal ablation, it is possible to protect the ureter with the use of intraprocedural retrograde pyeloperfusion. Cantwell et al⁷⁴ reported on early experience in using cooled 5% dextrose water, instilled by means of retrograde pyeloperfusion via a ureteral stent, during RFA of renal cell carcinomas located within 1.5 cm of the ureter. No patient developed ureteral

Figure 6 (A) Axial postcontrast T1 MR image of the abdomen demonstrates a large exophytic enhancing mass (arrow) arising from the lower pole of the right kidney. There is an area of hypoenhancement with surrounding fat stranding (arrowheads) from a previous radiofrequency ablation. (B) Axial noncontrast CT during cryoablation demonstrates three of the six cryoprobes (arrowheads) placed into the large right inferior pole renal mass (arrow). (C) Postprocedural non-contrast axial CT scan performed secondary to hypotension demonstrates a subcapsular renal hematoma (small arrows) that compresses the renal parenchyma medially (arrowheads). There is also a retroperitoneal hemorrhage (large arrow). The patient developed acute renal failure and required admission to the hospital as well as transfusion. CT, computed tomography; MR, magnetic resonance.

Figure 7 (A) Axial contrast-enhanced CT image of the abdomen demonstrates a cystic and solid left inferior pole renal mass (arrow). Of note, there is a cystic mass arising from the right kidney as well (arrowhead). The left renal mass was selected to be treated first. (B) Axial noncontrast-enhanced CT image of the abdomen demonstrates two of the seven cryoprobes (arrowheads) placed into the mass. A small gauge needle (arrow) was also placed to displace the colon by hydrodissection. (C) Axial contrast-enhanced CT of the abdomen 6 months after cryoablation demonstrates hypoenhancement and moderate to severe hydronephrosis of the left kidney (arrow). (D) Fluoroscopic-saved image during placement of a nephrostomy tube (arrowheads) demonstrates a tight stricture of the proximal left ureter (arrow). CT, computed tomography.

stricture out of 19 procedures. There was residual tumor in three patients, but these patients' tumors had complete ablation after a second RFA session.⁷⁴ In addition to injury to the ureter, urinomas may occur from perforation of any portion of the collecting system. Fortunately, this is an uncommon complication and most frequently results from damage to the calyces. An even rarer occurrence is that of an urinary-cutaneous fistula.^{29,75}

Extrarenal Complications

Bowel perforation may occur after ablation of a renal mass in the anterior aspect of the kidney due to its close proximity to bowel (→Fig. 8). A minimum of 5 mm of fat between the target tumor and adjacent bowel is suggested to ensure sufficient insulation to protect the bowel from thermal harm. Physical separation of the target tumor from adjacent bowel may reduce the risk of this complication. If there is insufficient fat between the target tumor and adjacent bowel, adjunctive maneuvers such as strategic lateral decubitus patient positioning, hydrodissection using 5% dextrose water, carbon dioxide injection, or balloon interposition are recommended to separate the kidney from the bowel.^{9,29} Thermal injury to the adjacent liver or spleen is not believed to be significant.^{42,76}

Genitofemoral nerve injury is another recognized risk of renal ablation. Thermal injury to the nerve, which originates from the upper part of the lumbar plexus and descends laterally along the psoas muscle, can cause chronic pain

and paresthesia in the ipsilateral groin. Injury to the psoas muscle itself can result in isolated hip flexion weakness. Sequelae of such nerve injuries are usually temporary, resolving within 6 months in most patients.^{9,67,68} Atwell et al reported that nerve injury occurred much more often after RFA (3.5%) than cryoablation (0.6%).⁶⁸ This may be explained, as the nature of the nerve tissue is more sensitive to heat than cold injury. One of the strategies to prevent this nerve injury is hydrodissection or carbon dioxide injection into the fat adjacent to the tumor to displace the ablation zone away from the psoas muscle. Another strategy is to employ the needle as a lever to displace the kidney, using the site of skin entry as a fixed point to torque the needle handle medially, leading to a lateral displacement of the renal tumor away from the psoas muscle.^{68,69,77}

Tumor seeding along the needle tract is an extremely rare complication of percutaneous renal ablation. Only five cases of tumor seeding along the needle tract from renal ablation (two RFA and three cryoablation) have been reported.^{68,78–81} It is important to be aware that a benign inflammatory tract mass may mimic needle tract seeding after renal ablation. An inflammatory tract mass appears as a solid geographic lesion with mild enhancement around the ablation tract on follow-up CT or MRI.^{9,69,82}

Pneumothorax has a reported incidence of 2% and usually develops when the renal tumor is in the upper pole kidney in close proximity to the lung base, where the posterior basal lung frequently interposes the pathway of the needle.⁷¹

Figure 8 (A) Axial postcontrast T1 MR image of the abdomen demonstrates a hypoenhancing renal mass (arrow), compatible with renal cell carcinoma. Note the proximity of the descending colon (arrowhead). (B) Axial noncontrast CT image during radiofrequency ablation demonstrates the radiofrequency ablation electrode (large arrows) within the left renal mass. A thin needle and fluid lateral to the left kidney (small arrows) demonstrate attempted hydrodissection of the colon (arrowhead) away from the electrode. (C) Axial contrast-enhanced CT image of the abdomen approximately 3 weeks after radiofrequency ablation demonstrates free gas and stool (arrows) in the retroperitoneum adjacent to the descending colon (arrowhead), compatible with colonic perforation. CT, computed tomography; MR, magnetic resonance.

However, pneumothorax may be artificially produced to protect lung tissue when there is no safe window due to the intervening lung base.⁸³ Mild asymptomatic pneumothoraces can usually be managed conservatively with bed rest and oxygen; however, moderate to severe pneumothorax typically requires percutaneous drainage.⁶⁹

Summary

RFA and MWA are widely accepted minimally invasive treatment modalities used in the treatment of liver tumors. In addition, RFA and cryoablation are two most commonly used ablation modalities in the treatment of small renal tumors. Each modality has unique technical features, and in general the expected complications are similar but not identical. Therefore, a thorough understanding of each modalities characteristic profile and complications is essential to maximize safety when performing the procedures as well as managing encountered complications properly.

References

- Liang P, Wang Y, Yu X, Dong B. Malignant liver tumors: treatment with percutaneous microwave ablation—complications among cohort of 1136 patients. *Radiology* 2009;251(3):933–940
- Solbiati L, Livraghi T, Goldberg SN, et al. Percutaneous radiofrequency ablation of hepatic metastases from colorectal cancer: long-term results in 117 patients. *Radiology* 2001;221(1):159–166
- Liang P, Dong B, Yu X, et al. Prognostic factors for survival in patients with hepatocellular carcinoma after percutaneous microwave ablation. *Radiology* 2005;235(1):299–307
- McDermott S, Gervais DA. Radiofrequency ablation of liver tumors. *Semin Intervent Radiol* 2013;30(1):49–55
- Lubner MG, Brace CL, Ziemlewicz TJ, Hinshaw JL, Lee FT Jr. Microwave ablation of hepatic malignancy. *Semin Intervent Radiol* 2013;30(1):56–66
- Hegg RM, Schmit GD, Boorjian SA, et al. Percutaneous renal cryoablation after partial nephrectomy: technical feasibility, complications and outcomes. *J Urol* 2013;189(4):1243–1248
- Gervais DA. Cryoablation versus radiofrequency ablation for renal tumor ablation: time to reassess? *J Vasc Interv Radiol* 2013;24(8):1135–1138
- Jiao DC, Zhou Q, Han XW, et al. Microwave ablation treatment of liver cancer with a 2,450-MHz cooled-shaft antenna: pilot study on safety and efficacy. *Asian Pac J Cancer Prev* 2012;13(2):737–742
- Venkatesan AM, Wood BJ, Gervais DA. Percutaneous ablation in the kidney. *Radiology* 2011;261(2):375–391
- Dodd GD III, Soulen MC, Kane RA, et al. Minimally invasive treatment of malignant hepatic tumors: at the threshold of a major breakthrough. *Radiographics* 2000;20(1):9–27
- Gervais DA, McGovern FJ, Wood BJ, Goldberg SN, McDougal WS, Mueller PR. Radio-frequency ablation of renal cell carcinoma: early clinical experience. *Radiology* 2000;217(3):665–672
- Buscarini L, Buscarini E, Di Stasi M, Vallisa D, Quaretti P, Rocca A. Percutaneous radiofrequency ablation of small hepatocellular carcinoma: long-term results. *Eur Radiol* 2001;11(6):914–921
- Dupuy DE, Goldberg SN. Image-guided radiofrequency tumor ablation: challenges and opportunities—part II. *J Vasc Interv Radiol* 2001;12(10):1135–1148
- Goldberg SN, Grassi CJ, Cardella JF, et al; Society of Interventional Radiology Technology Assessment Committee. Image-guided

- tumor ablation: standardization of terminology and reporting criteria. *J Vasc Interv Radiol* 2005;16(6):765–778
- 15 Ding J, Jing X, Liu J, et al. Complications of thermal ablation of hepatic tumours: comparison of radiofrequency and microwave ablative techniques. *Clin Radiol* 2013;68(6):608–615
 - 16 Lencioni R, Cioni D, Crocetti L, et al. Early-stage hepatocellular carcinoma in patients with cirrhosis: long-term results of percutaneous image-guided radiofrequency ablation. *Radiology* 2005;234(3):961–967
 - 17 Saldanha DF, Khiatani VL, Carrillo TC, et al. Current tumor ablation technologies: basic science and device review. *Semin Intervent Radiol* 2010;27(3):247–254
 - 18 McWilliams JP, Lee EW, Yamamoto S, Loh CT, Kee ST. Image-guided tumor ablation: emerging technologies and future directions. *Semin Intervent Radiol* 2010;27(3):302–313
 - 19 McWilliams JP, Yamamoto S, Raman SS, et al. Percutaneous ablation of hepatocellular carcinoma: current status. *J Vasc Interv Radiol* 2010;21(8, Suppl):S204–S213
 - 20 Martin RC, Scoggins CR, McMasters KM. Safety and efficacy of microwave ablation of hepatic tumors: a prospective review of a 5-year experience. *Ann Surg Oncol* 2010;17(1):171–178
 - 21 Lubner MG, Brace CL, Hinshaw JL, Lee FT Jr. Microwave tumor ablation: mechanism of action, clinical results, and devices. *J Vasc Interv Radiol* 2010;21(8, Suppl):S192–S203
 - 22 Brace CL, Laeseke PF, Sampson LA, Frey TM, van der Weide DW, Lee FT Jr. Microwave ablation with multiple simultaneously powered small-gauge triaxial antennas: results from an in vivo swine liver model. *Radiology* 2007;244(1):151–156
 - 23 McCarley JR, Soulen MC. Percutaneous ablation of hepatic tumors. *Semin Intervent Radiol* 2010;27(3):255–260
 - 24 Maybody M. An overview of image-guided percutaneous ablation of renal tumors. *Semin Intervent Radiol* 2010;27(3):261–267
 - 25 Atwell TD, Farrell MA, Leibovich BC, et al. Percutaneous renal cryoablation: experience treating 115 tumors. *J Urol* 2008;179(6):2136–2140, discussion 2140–2141
 - 26 Gervais DA, McGovern FJ, Arellano RS, McDougal WS, Mueller PR. Renal cell carcinoma: clinical experience and technical success with radio-frequency ablation of 42 tumors. *Radiology* 2003;226(2):417–424
 - 27 Buscarini E, Buscarini L. Radiofrequency thermal ablation with expandable needle of focal liver malignancies: complication report. *Eur Radiol* 2004;14(1):31–37
 - 28 Nemcek AA. Complications of radiofrequency ablation of neoplasms. *Semin Intervent Radiol* 2006;23(2):177–187
 - 29 Howenstein MJ, Sato KT. Complications of radiofrequency ablation of hepatic, pulmonary, and renal neoplasms. *Semin Intervent Radiol* 2010;27(3):285–295
 - 30 Rhim H, Yoon KH, Lee JM, et al. Major complications after radiofrequency thermal ablation of hepatic tumors: spectrum of imaging findings. *Radiographics* 2003;23(1):123–134, discussion 134–136
 - 31 Takaki H, Yamakado K, Nakatsuka A, et al. Frequency of and risk factors for complications after liver radiofrequency ablation under CT fluoroscopic guidance in 1500 sessions: single-center experience. *AJR Am J Roentgenol* 2013;200(3):658–664
 - 32 Livraghi T, Meloni F, Solbiati L, Zanus G; Collaborative Italian Group using AMICA system. Complications of microwave ablation for liver tumors: results of a multicenter study. *Cardiovasc Intervent Radiol* 2012;35(4):868–874
 - 33 Koda M, Murawaki Y, Hirooka Y, et al. Complications of radiofrequency ablation for hepatocellular carcinoma in a multicenter study: An analysis of 16 346 treated nodules in 13 283 patients. *Hepatol Res* 2012;42(11):1058–1064
 - 34 Bertot LC, Sato M, Tateishi R, Yoshida H, Koike K. Mortality and complication rates of percutaneous ablative techniques for the treatment of liver tumors: a systematic review. *Eur Radiol* 2011;21(12):2584–2596
 - 35 Kong WT, Zhang WW, Qiu YD, et al. Major complications after radiofrequency ablation for liver tumors: analysis of 255 patients. *World J Gastroenterol* 2009;15(21):2651–2656
 - 36 Poggi G, Riccardi A, Quaretti P, et al. Complications of percutaneous radiofrequency thermal ablation of primary and secondary lesions of the liver. *Anticancer Res* 2007;27(4C):2911–2916
 - 37 Livraghi T, Solbiati L, Meloni MF, Gazelle GS, Halpern EF, Goldberg SN. Treatment of focal liver tumors with percutaneous radiofrequency ablation: complications encountered in a multicenter study. *Radiology* 2003;226(2):441–451
 - 38 de Baère T, Risse O, Kuoch V, et al. Adverse events during radiofrequency treatment of 582 hepatic tumors. *AJR Am J Roentgenol* 2003;181(3):695–700
 - 39 Zhang L, Wang N, Shen Q, Cheng W, Qian GJ. Therapeutic efficacy of percutaneous radiofrequency ablation versus microwave ablation for hepatocellular carcinoma. *PLoS ONE* 2013;8(10):e76119
 - 40 Akahane M, Koga H, Kato N, et al. Complications of percutaneous radiofrequency ablation for hepato-cellular carcinoma: imaging spectrum and management. *Radiographics* 2005;25(Suppl 1):S57–S68
 - 41 Kim YS, Rhim H, Sung JH, et al. Bronchobiliary fistula after radiofrequency thermal ablation of hepatic tumor. *J Vasc Interv Radiol* 2005;16(3):407–410
 - 42 Rhim H, Dodd GD III, Chintapalli KN, et al. Radiofrequency thermal ablation of abdominal tumors: lessons learned from complications. *Radiographics* 2004;24(1):41–52
 - 43 Curley SA, Marra P, Beatty K, et al. Early and late complications after radiofrequency ablation of malignant liver tumors in 608 patients. *Ann Surg* 2004;239(4):450–458
 - 44 Kim SK, Lim HK, Ryu JA, et al. Radiofrequency ablation of rabbit liver in vivo: effect of the Pringle maneuver on pathologic changes in liver surrounding the ablation zone. *Korean J Radiol* 2004;5(4):240–249
 - 45 Ng KK, Lam CM, Poon RT, Shek TW, Fan ST, Wong J. Delayed portal vein thrombosis after experimental radiofrequency ablation near the main portal vein. *Br J Surg* 2004;91(5):632–639
 - 46 Shen P, Fleming S, Westcott C, Challa V. Laparoscopic radiofrequency ablation of the liver in proximity to major vasculature: effect of the Pringle maneuver. *J Surg Oncol* 2003;83(1):36–41
 - 47 Kim YS, Rhim H, Lim HK, Choi D, Lee WJ, Kim SH. Hepatic infarction after radiofrequency ablation of hepatocellular carcinoma with an internally cooled electrode. *J Vasc Interv Radiol* 2007;18(9):1126–1133
 - 48 Ogawa T, Kawamoto H, Kobayashi Y, et al. Prevention of biliary complication in radiofrequency ablation for hepatocellular carcinoma-cooling effect by endoscopic nasobiliary drainage tube. *Eur J Radiol* 2010;73(2):385–390
 - 49 Elias H, Sideris L, Pocard M, Dromain C, De Baere T. Intraductal cooling of the main bile ducts during radiofrequency ablation prevents biliary stenosis. *J Am Coll Surg* 2004;198(5):717–721
 - 50 Shibata T, Yamamoto Y, Yamamoto N, et al. Cholangitis and liver abscess after percutaneous ablation therapy for liver tumors: incidence and risk factors. *J Vasc Interv Radiol* 2003;14(12):1535–1542
 - 51 Korutz AW, Sato KT. Radiofrequency ablation of a solitary liver metastasis complicated by colonic perforation. *Semin Intervent Radiol* 2011;28(2):171–174
 - 52 Meloni MF, Goldberg SN, Moser V, Piazza G, Livraghi T. Colonic perforation and abscess following radiofrequency ablation treatment of hepatoma. *Eur J Ultrasound* 2002;15(1–2):73–76
 - 53 Yamakado K, Nakatsuka A, Akeboshi M, Takeda K. Percutaneous radiofrequency ablation of liver neoplasms adjacent to the gastrointestinal tract after balloon catheter interposition. *J Vasc Interv Radiol* 2003;14(9, Pt 1):1183–1186
 - 54 Diehn FE, Neeman Z, Hvizda JL, Wood BJ. Remote thermometry to avoid complications in radiofrequency ablation. *J Vasc Interv Radiol* 2003;14(12):1569–1576

- 55 Livraghi T, Lazzaroni S, Meloni F, Solbiati L. Risk of tumour seeding after percutaneous radiofrequency ablation for hepatocellular carcinoma. *Br J Surg* 2005;92(7):856–858
- 56 Jaskolka JD, Asch MR, Kachura JR, et al. Needle tract seeding after radiofrequency ablation of hepatic tumors. *J Vasc Interv Radiol* 2005;16(4):485–491
- 57 Yu J, Liang P, Yu XL, Cheng ZG, Han ZY, Dong BW. Needle track seeding after percutaneous microwave ablation of malignant liver tumors under ultrasound guidance: analysis of 14-year experience with 1462 patients at a single center. *Eur J Radiol* 2012;81(10):2495–2499
- 58 Yamakado K, Akeboshi M, Nakatsuka A, et al. Tumor seeding following lung radiofrequency ablation: a case report. *Cardiovasc Intervent Radiol* 2005;28(4):530–532
- 59 Llovet JM, Vilana R, Brú C, et al; Barcelona Clinic Liver Cancer (BCLC) Group. Increased risk of tumor seeding after percutaneous radiofrequency ablation for single hepatocellular carcinoma. *Hepatology* 2001;33(5):1124–1129
- 60 Espinoza S, Briggs P, Duret JS, Lapeyre M, de Baère T. Radiofrequency ablation of needle tract seeding in hepatocellular carcinoma. *J Vasc Interv Radiol* 2005;16(5):743–746
- 61 Goldberg SN, Solbiati L, Halpern EF, Gazelle GS. Variables affecting proper system grounding for radiofrequency ablation in an animal model. *J Vasc Interv Radiol* 2000;11(8):1069–1075
- 62 Steinke K, Gananadha S, King J, Zhao J, Morris DL. Dispersive pad site burns with modern radiofrequency ablation equipment. *Surg Laparosc Endosc Percutan Tech* 2003;13(6):366–371
- 63 Andreano A, Galimberti S, Franza E, et al. Percutaneous microwave ablation of hepatic tumors: prospective evaluation of postablation syndrome and postprocedural pain. *J Vasc Interv Radiol* 2014;25(1):97–105, e1–e2
- 64 Dodd GD III, Napier D, Schoolfield JD, Hubbard L. Percutaneous radiofrequency ablation of hepatic tumors: postablation syndrome. *AJR Am J Roentgenol* 2005;185(1):51–57
- 65 Wah TM, Arellano RS, Gervais DA, et al. Image-guided percutaneous radiofrequency ablation and incidence of post-radiofrequency ablation syndrome: prospective survey. *Radiology* 2005;237(3):1097–1102
- 66 Abbosh PH, Bhayani SB. Thermoablation of renal masses: the urologists perspective. *Semin Intervent Radiol* 2011;28(4):361–366
- 67 Georgiades CS, Hong K, Bizzell C, Geschwind JF, Rodriguez R. Safety and efficacy of CT-guided percutaneous cryoablation for renal cell carcinoma. *J Vasc Interv Radiol* 2008;19(9):1302–1310
- 68 Atwell TD, Carter RE, Schmit GD, et al. Complications following 573 percutaneous renal radiofrequency and cryoablation procedures. *J Vasc Interv Radiol* 2012;23(1):48–54
- 69 Park BK, Kim CK. Complications of image-guided radiofrequency ablation of renal cell carcinoma: causes, imaging features and prevention methods. *Eur Radiol* 2009;19(9):2180–2190
- 70 Gervais DA, McGovern FJ, Arellano RS, McDougal WS, Mueller PR. Radiofrequency ablation of renal cell carcinoma: part 1, Indications, results, and role in patient management over a 6-year period and ablation of 100 tumors. *AJR Am J Roentgenol* 2005;185(1):64–71
- 71 Zagoria RJ, Traver MA, Werle DM, Perini M, Hayasaka S, Clark PE. Oncologic efficacy of CT-guided percutaneous radiofrequency ablation of renal cell carcinomas. *AJR Am J Roentgenol* 2007;189(2):429–436
- 72 Woodrum DA, Atwell TD, Farrell MA, Andrews JC, Charboneau JW, Callstrom MR. Role of intraarterial embolization before cryoablation of large renal tumors: a pilot study. *J Vasc Interv Radiol* 2010;21(6):930–936
- 73 Park BK, Kim CK, Lim HK. Renal infarction resulting from segmental arterial injury during radiofrequency ablation of renal tumor in patient with a single kidney. *Urology* 2009;73(2):e9–e11
- 74 Cantwell CP, Wah TM, Gervais DA, et al. Protecting the ureter during radiofrequency ablation of renal cell cancer: a pilot study of retrograde pyeloperfusion with cooled dextrose 5% in water. *J Vasc Interv Radiol* 2008;19(7):1034–1040
- 75 Hui GC, Tuncali K, Tatli S, Morrison PR, Silverman SG. Comparison of percutaneous and surgical approaches to renal tumor ablation: metaanalysis of effectiveness and complication rates. *J Vasc Interv Radiol* 2008;19(9):1311–1320
- 76 Zagoria RJ. Imaging-guided radiofrequency ablation of renal masses. *Radiographics* 2004;24(Suppl 1):S59–S71
- 77 Boss A, Clasen S, Kuczyk M, et al. Thermal damage of the genitofemoral nerve due to radiofrequency ablation of renal cell carcinoma: a potentially avoidable complication. *AJR Am J Roentgenol* 2005;185(6):1627–1631
- 78 Mayo-Smith WW, Dupuy DE, Parikh PM, Pezzullo JA, Cronan JJ. Imaging-guided percutaneous radiofrequency ablation of solid renal masses: techniques and outcomes of 38 treatment sessions in 32 consecutive patients. *AJR Am J Roentgenol* 2003;180(6):1503–1508
- 79 Akhavein A, Neuberger MM, Dahm P. Tumour-seeding: a rare complication of ablative therapy for clinically localised renal cell carcinoma. *BMJ Case Rep* 2012;2012. pii:bcr2012006948
- 80 Krambeck AE, Farrell MA, Charboneau JW, Frank I, Zincke H. Intraperitoneal drop metastasis after radiofrequency ablation of pararenal tumor recurrences. *Urology* 2005;65(4):797
- 81 Sainani NI, Tatli S, Anthony SG, Shyn PB, Tuncali K, Silverman SG. Successful percutaneous radiologic management of renal cell carcinoma tumor seeding caused by percutaneous biopsy performed before ablation. *J Vasc Interv Radiol* 2013;24(9):1404–1408
- 82 Lokken RP, Gervais DA, Arellano RS, et al. Inflammatory nodules mimic applicator track seeding after percutaneous ablation of renal tumors. *AJR Am J Roentgenol* 2007;189(4):845–848
- 83 Ahrar K, Matin S, Wallace MJ, Gupta S, Hicks ME. Percutaneous transthoracic radiofrequency ablation of renal tumors using an iatrogenic pneumothorax. *AJR Am J Roentgenol* 2005;185(1):86–88